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PRELIMINARY GUIDELINES FOR ESTIMATING THE SURVIVAL OF FIRE-DAMAGED TREES

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The forest fires of September 1955 in California have created an immediate interest not only in salvaging the timber killed by the fires but also in saving the trees that are still alive and likely to survive to provide future seed sources within the burned areas. Even with all of the help that nature can provide, the task of establishing new forests on the burned ground will be a tremendous one, beyond present physical and financial possibilities of complete attainment. Every tree that can be saved as a source of seed for natural reproduction will be needed.

In 1939, following early work by forest entomologists, [1] [2] [3] the San Francisco Branch, Division of Forest Pathology, U. S. Department of Agriculture, now a part of the California Forest and Range Experiment Station, began a study of the survival of ponderosa and Jeffrey pines following damage by fire, in cooperation with the Forest Service and the National Park Service. Sample injured trees on selected fresh burns were examined each year until mortality had returned to normal, usually in 3 to 4 years. Later, the study was extended to include other conifers. Observations have been concluded on 29 burns, located in 12 national forests in California and in Yosemite National Park, but the results have not yet been completely compiled or summarized. In the course of the studies, however, a number of generalizations concerning survival from fire injury have emerged. These generalizations are outlined here as an aid to field men in salvage work on current burns. The conclusions are subject to modification or amendment when the complete results of the study become available although no material changes are anticipated.

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[1] Miller, J. M. and Patterson, J. E. Preliminary studies on the relation of fire injury to bark beetle attack in western yellow pine. Jour. Agr. Res. 34: 597-613, illus. 1927.

[2] Miller, J. M. Why the western pine beetle follows fire. Forest Worker 5(4): 16-17. July 1929.

[3] Salman, K. A. Entomological factors affect salvage of fire injured trees. Jour. Forestry 32: 1016-1017. 1934.

The California Forest and Range Experiment Station is maintained at Berkeley in cooperation with the University of California.

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Tree Survival and Date of the Fire

The time of year at which a fire occurs has a strong influence on the degree of injury which a tree can endure, particularly ponderosa and Jeffrey pines. A tree is most vulnerable to damage from fire when it is actively growing, both in diameter and in height. During this time food materials are being used at a rapid rate, food reserves of starch and sugars are at a minimum, and growing points are tender and unprotected. In California, growth is usually at a maximum in June, 4/ and trees are much more susceptible to fire damage then than at other times of the year.

As the season progresses, first shoot growth and later diameter growth cease. Reserves in the form of starch begin to accumulate for the initiation of growth the following year. Terminal buds form and in ponderosa and Jeffrey pines become quite well protected by scales, enabling them to withstand more heat than needles do without significant damage. The growth period varies somewhat with elevation, species, and season, but by September growth is usually complete or nearly so and terminal buds have been formed, making the trees better able to survive fire than during the season of active growth. However, food reserves continue to accumulate during the fall. Thus the later the fire, the better the tree is prepared to survive heavy defoliation.

The time of year at which the fire occurs also influences subsequent insect attack. In an early fire at low to moderate elevations, such as the Northfork fire of June 1924 studied by Miller, insects become well established in the burn during the summer and fall and maximum losses in trees not killed outright by the fire occur the first year after it. As Miller and Patterson reported, when fires occur later in the season, as in late August or in September, attack by bark beetles depends on whether or not seasonal flights take place following the fire. When late season attacks occur during the year of the fire they tend to be confined to the smaller, mortally damaged trees of 12 inches or more in breast-high diameter, and maximum mortality in trees not killed outright may be delayed until the second year after the fire.

4/ Fowells, H. A. The period of seasonal growth of ponderosa pine and associated species. Jour. Forestry 39: 601-608. 1941.

Survival in Relation to Growth Rate and Site

Survival possibilities are strongly correlated with the vigor of the tree before the fire, and vigor is influenced both by the age of the tree and the quality of the site on which it is growing. Relatively young, thrifty trees on good sites have the best chances; and old, overmature trees, such as those in Class 5 of the Dunning classification, on poor sites have the poorest chances for survival from serious fire injury. Young, thrifty trees, as Dunning class 1's, on good sites sometimes survive the complete killing of foliage in a late-season fire if 60 percent or more of the buds remain alive.

Survival in Relation to Crown and Bud Kill

In marking trees to cut or leave on a burn, the tendency is to give too much weight to the percentage of remaining live crown, especially in ponderosa and Jeffrey pines, and not enough weight to other features such as bud kill. In these two pines our studies have shown that bud kill is much more important than foliage kill in determining survival chances. Other conifers, such as sugar pine, white fir, Douglas-fir, and incense-cedar, have much smaller, less well-protected buds, and their twigs are much more slender. In consequence foliage kill and bud kill differ very little in these other species, and the percentage of green crown is a good index of the crown that will be available to the tree for the next year or two.

Conditions Necessary for Survival

No one percentage of live crown can be used as a standard for judging the survival possibilities of a scorched tree. The time during the season at which the fire occurs, the age and growth vigor of the tree preceding the fire, the tree species, and its susceptibility to insect attack following injury all influence the amount of crown needed to pull the tree through if there has been no severe cambium injury. Basically, as Miller has pointed out for ponderosa pines, it is the amount of growth made by the trees following the fire that largely determines whether or not the trees will later succumb to bark beetle attacks. He found that the trees attacked were those that had made little or no growth in growing seasons subsequent to the fire.

Thrifty ponderosa pines scorched in late August or September fires will usually survive if more than 50 percent of the buds and twigs and about 5 percent or more of the foliage remain alive. Old, overmature ponderosa or Jeffrey pines on burns in "East Side" timber may require as much as 25 percent of green crown for survival. For other species 30 to 40 percent of green crown is needed.

Judging Degree of Crown Injury

On ponderosa pine the percentage of live buds is sometimes difficult to estimate for the first month or so after a fire. Twigs from which needles have been burned are sure to be dead. Twigs on which needles are still present but show a set in an abnormal position, usually bent in the direction of run of the fire, are also certain to be dead. If, with field glasses, green bases can be found on part of the needles, all the twigs on that part of the branch or the twigs nearby on adjacent branches are likely to be alive, irrespective of whether or not all show green needle bases close to the terminals. Differentiation becomes much easier after a few months have elapsed because dead foliage is shed from the live twigs and is retained on dead twigs, thinning out portions of the crown where the foliage but not the buds and twigs have been killed. This thinning is brought about by the formation of abcission layers at the bases of the dead needles on living twigs, whereas no such layers can be formed on dead twigs. Individual ponderosa pines may differ, however, in the readiness with which abcission and the accompanying thinning of the crown occurs. Abcission and dropping of the dead foliage on live limbs also occurs on other species and aids in differentiating the live parts of the crown.

General indications of fire intensity are of value in suggesting the degree of twig and bud kill. If no needles have been burned off or only those on a few lower branches and if the greater part of the foliage on the trees hangs in a natural position, the percentage of live buds and twigs is likely to be high even though not much green foliage is evident. If most of the trees appear to be completely killed and there is evidence that flames actually reached the crowns, few of the twigs on trees that still retain most of their scorched foliage are likely to be alive unless some special feature of the surroundings has afforded a degree of protection not received by other trees in the vicinity.

Survival in Relation to Cambium Injury

Tree bark varies greatly within species--in thickness, and in width and depth of crevices between bark ridges. Between species it differs in insulating quality. Forest fuels also vary in distribution, including the amount of ground cover, litter and duff accumulations, and, in cut-over stands, the amount of logging debris. Thus in uneven-aged stands of mixed species swept by fire, injury to cambium is likely to show great variation.

Cambium injury is ordinarily heaviest on the lee side of the tree with respect to the direction of run of the fire and on the uphill side of trees located on slopes. Killed patches of cambium are usually widest just above ground level and taper from there upward.

Sugar pine constitutes a special case. In proportion to diameter, sugar pine has thinner, denser bark, with poorer insulating capacity than the bark of associated conifers. Moreover, the bark scales tend to flake off and accumulate at ground level around the flared trunk. During a fire, this ring of loose scales burns slowly, producing a concentrated heat that often kills a ring of cambium only a few inches in height around the greater part of the base of the tree, even where the bark shows only minor scorching on the surface above this level. Large sugar pines can occasionally be found with scarcely a scorched needle and with little blackening of the trunks but completely girdled at the ground level by a narrow band of killed cambium. However, sugar pines have demonstrated that they can survive girdling of this type up to 75 percent or more of the circumference and make good recovery if accompanying crown injury is not too severe and growth vigor prior to the fire was good.

Effect on Insect Attack

When not so extensive as to directly threaten the life of the tree and where seed sources are badly needed, cambium killing is of chief interest because of its possible effect on subsequent insect attack. On the Northfork burn of 1924, Miller reported for ponderosa pine that basal wounds due to the burning of one side of the trunk near the ground did not attract primary bark beetles unless accompanied by the scorching of foliage and of cambium in the upper trunk. On the Modoc National Forest, Salman found that trees with moderate to heavy cambium injury were more susceptible to bark beetle attack than trees defoliated to the same degree by fire but with little or no cambium injury.

Our own observations have shown that strip injury to cambium under crevices or moderate basal patch killing have little influence on subsequent insect hazard except where a large population of red turpentine beetles (*Dendroctonus valens* Lec.) has built up in stumps from recent logging in the vicinity. Even under such conditions the insect hazard is increased only for trees of rather marginal condition with respect to survival. Cambium injury at some distance from the ground, when accompanied by heavy foliage killing, is very likely to lead to subsequent bark beetle attack, as indicated by Miller.

Judging Degree of Cambium Injury

The degree and location of external charring of the bark provides some indication of probable cambium injury, though thick-barked trees will sometimes withstand rather heavy external charring without serious damage to the cambium. Scattered resin drops over charred bark of lower trunks are usually not significant because they originate chiefly from branch stubs or the bases of lower branches, and not from the bark of the trunk itself. Concentrated resinflow that can definitely be seen to be coming from the bark itself, on the other hand, generally indicates a killed area of cambium. It usually issues from calluses around scars from previous fires, from old mistletoe cankers on the trunk, or from other irregularities in the normal trunk contours. Burned chunks or down logs close to the base of a tree almost always indicate heavy kill of the cambium facing such objects.

Relation of Insects to Survival

Experience in the course of the study bears out the statements by Miller that roundheaded and flatheaded borers (Cerambycidae and Buprestidae) are the first insects to invade burned stands, along with a few red turpentine beetles. The borers at first enter small and medium sized trees completely killed by the fire; whereas the red turpentine beetles invade the bases of trees in which most of the cambium is still alive but with patch injury.

Primary bark beetles, such as the western pine beetle (*Dendroctonus brevicomis* Lec.) and the mountain pine beetle (*D. monticolae* Hopk.) are not immediately attracted to a burn; when they later invade, they generally confine their first attacks to the smaller, mortally injured trees with green cambium, trees with little or no chance of survival regardless of insect invasions. The intensity of the ultimate influx depends on the size of the burn, the status of the bark beetle population in surrounding green timber, and the percentage of trees not initially killed but damaged severely enough to reduce growth to a minimum. After late-season fires, trees that would normally recover if not invaded by bark beetles are ordinarily not attacked until the latter part of the year after the fire, and frequently not until the second year.

The appearance of pitch tubes of the red turpentine beetle around the base of a tree does not mean that the tree is doomed. If the tubes are not numerous or if they are confined to scattered exposed locations around the base, they are likely to have little effect on survival. In areas not previously logged, attacks by these beetles tend to be concentrated in trees that were high in insect risk before the fire.

The survival chances of white fir after severe fire-caused injury seem to depend on whether or not the trunks are invaded by ambrosia beetles during the first or second summer following the fire. Limited evidence from the studies suggests that firs in the colder locations, such as on the east slope of the Sierra Nevada, are not likely to be invaded by ambrosia beetles; whereas those situated in the milder climate of middle elevations on the west slope may be invaded. If invasion occurs, as indicated by small deposits on the bark of the powdery frass ejected from the gallery mouths by the beetles, the tree generally succumbs.

Estimating and Marking Burned Timber

On portions of a burn where the initial kill is not complete, the average tendency is to underestimate recovery potential and to overestimate the volume requiring salvage. Accordingly, sufficient leeway should be allowed in such estimates to permit later modification if the objective is to retain all trees likely to survive to provide future seed sources or volume for a future cut.

Marking, either on a cut or leave basis, should not be extended far in advance of actual logging needs. In particular, trees should not be marked one season that will not be logged until the next. By delaying, the marker will be able to take advantage of the improved chances for judging bud and cambium kill that come with elapsed time after a fire.

Marking is best done with a two-man crew, one to examine the crowns from a distance, with the aid of field glasses where necessary, and the other to examine the trunks and apply the marking symbols. Crowns should be viewed at right angles to the direction of run of the fire, if possible, so that both the windward and lee sides can be seen. Good light is essential. Marking in fire-damaged timber should not be attempted on cloudy days, unless absolutely unavoidable, as evidences of green in partially scorched foliage are almost impossible to see against a cloudy sky.

At the start of marking in burned timber, the condition of the cambium in a number of representative trees should be investigated to determine the amount and distribution of damage and its relation to position on the trunk and degree of surface charring of the bark. This is done by chopping into the bark with the point of an axe. Using the conditions found in this sampling as a guide, all doubtful cases of cambium injury should be investigated as far as practicable in the subsequent marking.

To obtain the benefit of maximum survival and regeneration, along with maximum salvage, two-stage logging is necessary. The survival of badly damaged trees is often a matter of chance that cannot be accurately assessed in advance. Weather conditions the year following the fire, the intensity and character of the insect build-up in the burn, the degree of exposure as compared with former conditions, and the actual status of cambium injury as compared with the status judged by surface indications or limited sampling, all may influence survival one way or the other. If marking is done on a basis to include all trees that are likely to die, it will also inevitably include numbers of trees that would live. Moreover, some of the trees that succumb the second year after the fire may produce heavy seed crops the preceding fall. In the course of the study, striking examples have been encountered of reproduction from seed produced a year after the fire by trees that ultimately succumbed. If such trees are cut during the initial logging, the chance to obtain reproduction from them is lost.

In a mixed stand, two-stage logging also permits the leaving of the less valuable species and those in which degrade from stain is not a factor, such as the firs, until the second round, concentrating on rapid removal of the higher value species, such as the pines, in which degrade from stain is a consideration affecting the value of the product.

Deterioration of Injured Trees

Deterioration of timber killed outright by fire in California has been reported by Kimmey [5]. Deterioration in trees which die later will be delayed as compared with the initially killed trees because deterioration does not start until the injured tree is invaded by bark beetles. Bark beetles usually do not invade until a year or two after the fire. Once the attack has occurred, deterioration may be slightly more rapid than in the completely killed timber reported on by Kimmey, because insect invasion into the latter is not immediate nor at the same time into trees of all sizes.

Wherever possible, areas of complete kill should be logged first in a burn, because it is here that deterioration will be most rapid. Similarly, deterioration will start sooner in small killed timber than in large. The beetles that provide entrance for the deteriorating fungi or that bore into the sapwood of the killed trees concentrate first on the smaller diameter trees, which usually have thinner bark than large, mature trees of the same species.

Thus, if maximum salvage with the least deterioration is to be secured, areas of completely killed small-diameter timber should be salvaged first; then the completely killed large timber; and last, the stands in which killing has not been complete. On past burns initial logging has usually been concentrated in the large mature timber, probably in consideration of the fact that these were the trees of the highest value in which the operator was most interested. The smaller timber was generally left to the last, by which time some of it had become unsalvageable or of very marginal value. By a better distribution of logging with respect to deterioration hazard, a greater maximum volume could usually have been salvaged without serious deterioration.

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[5] Kimmey, James W. Rate of deterioration of fire-killed timber in California. U. S. Dept. Agr. Circ. 962. 22 pp., illus. 1955.

Summary

Briefly, the study of fire-damaged trees in California suggests the following preliminary generalizations to aid in estimating the probability of survival:

1. The later the fire in the season, the better the chances for survival of trees from severe fire injury and the less the chance for attack by primary bark beetles that same season.

2. The younger and thriftier the tree before the fire and the better the site, the better the prospects for recovery.

3. In ponderosa and Jeffrey pines, bud kill is more important than foliage kill in determining survival. More than 50 percent of live buds are usually needed for a tree to survive.

4. In other species, bud kill and foliage kill are of nearly the same effect because buds and twigs are small and poorly protected. In these species, 30 to 40 percent of green crown is ordinarily needed for survival.

5. Cambium injury can be judged only approximately. One-sided basal wounds do not influence survival unless combined with heavy crown injury, poor initial tree vigor, or damage to the cambium high on the trunk.

6. Moderate red turpentine beetle attacks can be tolerated. Maximum insect-caused losses in trees not initially killed by the fire generally occur late in the first year or during the second year after the fire.

7. The general tendency is to overestimate mortality in cruising a burn after a fire. Marking should not be in advance of actual needs because the longer it can be delayed the plainer the indicators of actual damage become. It requires good light.

8. Maximum survival, salvage, and opportunities for reproduction are achieved when logging is in two stages, the first stage confined to completely killed pines and the second to other species and to pines that have died during the intervening time.